SECTION 9 FIRE DESIGN

9.1 REQUIREMENTS

This Section applies to the design of cold-formed steel building members such as beams/columns or floors/load-bearing walls that are required to have a fire resistance level (FRL) based on structural adequacy.

Since thin-walled cold-formed steel structural members have a high exposed surface area to mass ratio, the temperature development in these members is likely to be rapid and high. Hence they are often located within or protected by fire-resistant barriers when they are required to have a FRL. This Section applies to such protected cold-formed steel structural members.

The protected cold-formed steel structural members shall be designed to have a period of structural adequacy (PSA) equal to or greater than the required FRL. The PSA shall be determined in accordance with Clause 9.3. using the elevated temperature mechanical properties of cold-formed steels as specified in Clause 9.4 and the temperature—time relationship of cold-formed steel structural members in the standard fire based on Clause 9.7.

Connections shall be designed for fire in accordance with Clause 9.9.

9.2 DEFINITIONS

For the purposes of this Section, the definitions below apply.

9.2.1 Fire resistance level (FRL)

The fire resistance period for structural adequacy only, in minutes, which is required to be attained in the standard fire test.

9.2.2 Load ratio

The ratio of the design action on the member under the design load for fire specified in AS/NZS 1170.1 to the design capacity of the member at ambient temperature.

9.2.3 Period of structural adequacy (PSA)

The time in minutes, for the member to reach the limit state of structural adequacy in the standard fire test.

9.2.4 Prototype

A test specimen representing a cold-formed steel structural member and its fire protection system in the standard fire test.

9.2.5 Standard fire test

The fire resistance test specified in AS 1530.4.

9.2.6 Structural adequacy

The ability of the member in the standard fire test to carry the applied test load determined based on the member design action for fire specified in AS/NZS 1170.1.

9.3 DETERMINATION OF THE PERIOD OF STRUCTURAL ADEQUACY

The period of structural adequacy (PSA) shall be determined using one of the following methods:

(a) By direct application of a single standard fire test in accordance with Clause 9.8.

(b) By simple calculations using the following two steps:

(i) Determine the limiting temperature of cold-formed steel structural member in accordance with Clause 9.4

(ii) Determine the PSA as the time from the start of the standard fire test to the time at which the limiting steel temperature is reached by using the temperature-time relationship determined in accordance with Clause 9.7.

(c) By member capacity calculations at elevated temperatures in accordance with advanced structural analysis or Clause 9.5. based on the following two steps:

(i) Determine the load-bearing capacity of cold-formed steel structural member at a time equal to FRL in the standard fire test by using its temperature-time relationship obtained in accordance with Clause 9.7 and the elevated temperature mechanical properties in accordance with Clause 9.4.

(ii) The load-bearing capacity thus determined shall be equal to or greater than the design action on the member under the design load for fire. Alternatively. determine the time at which the above condition is met, which is PSA.

(d) Based on fire test results of similar cold-formed steel structural members and/or the use of advanced thermal and structural analyses. The methods in Appendix B shall be used for elevated temperature exposure by including the elevated temperature effects on the mechanical and thermal properties of steel as specified in Clause 9.4 and thermal deformations (if any). Advanced structural analysis shall simulate the behaviour of the cold-formed steel structural member restrained by its protection systems through the inclusion of buckling and non-linear material and geometric effects when exposed to the required elevated temperature-time exposure. Advanced thermal analysis based on

established heat transfer principles shall be used to determine the temperature-time relationships for the protected cold-formed structural steel member exposed to the standard fire time-temperature curve on one side using the elevated temperature thermal properties of steel and protective materials. Advanced analyses shall be validated using representative standard fire test results.

9.4 ELEVATED TEMPERATURE MECHANICAL AND THERMAL PROPERTIES

9.4.1 General

Elevated temperature mechanical properties of cold-formed steels depend on the chemical composition. level of cold working and associated manufacturing processes. This Section includes the predictive equations for cold-formed steels to AS 1397. G450 grade and above are considered as high strength steels. For unidentified steels. elevated temperature tensile tests shall be undertaken.

9.4.2 Variation of yield stress with temperature

The influence of temperature (T) on the yield stress is defined by a reduction factor $\left(\frac{f_{y,T}}{f_{y,20}}\right)$ as follows. This relationship is shown in Figure 9.4.2.

For high strength steels to AS 1397:

$$20\ °C \le T < 300\ °C \quad \frac{f_{y,T}}{f_{y,20}} = -0.000179\ T + 1.00358 \qquad ...9.4.2(1)$$

$$300\ °C \le T < 600\ °C \quad \frac{f_{y,T}}{f_{y,20}} = -0.0028\ T + 1.79 \qquad ...9.4.2(2)$$

$$600\ °C \le T < 800\ °C \quad \frac{f_{y,T}}{f_{y,20}} = -0.0004\ T + 0.35 \qquad ...9.4.2(3)$$

For low strength steels to AS 1397:

$$20\ °C \le T < 200\ °C \quad \frac{f_{y,T}}{f_{y,20}} = -0.0005\,T + 1.01 \qquad \text{...9.4.2(4)}$$

$$200\ °C \le T < 800\ °C \quad \frac{f_{y,T}}{f_{y,20}} = 25\left(1.16 - T^{0.222}\right) \qquad \text{...9.4.2(5)}$$

where

$f_{y,T}$ = yield stress of steel at $T\,°C$

$f_{y,20}$ = yield stress of steel at $20\ °C$

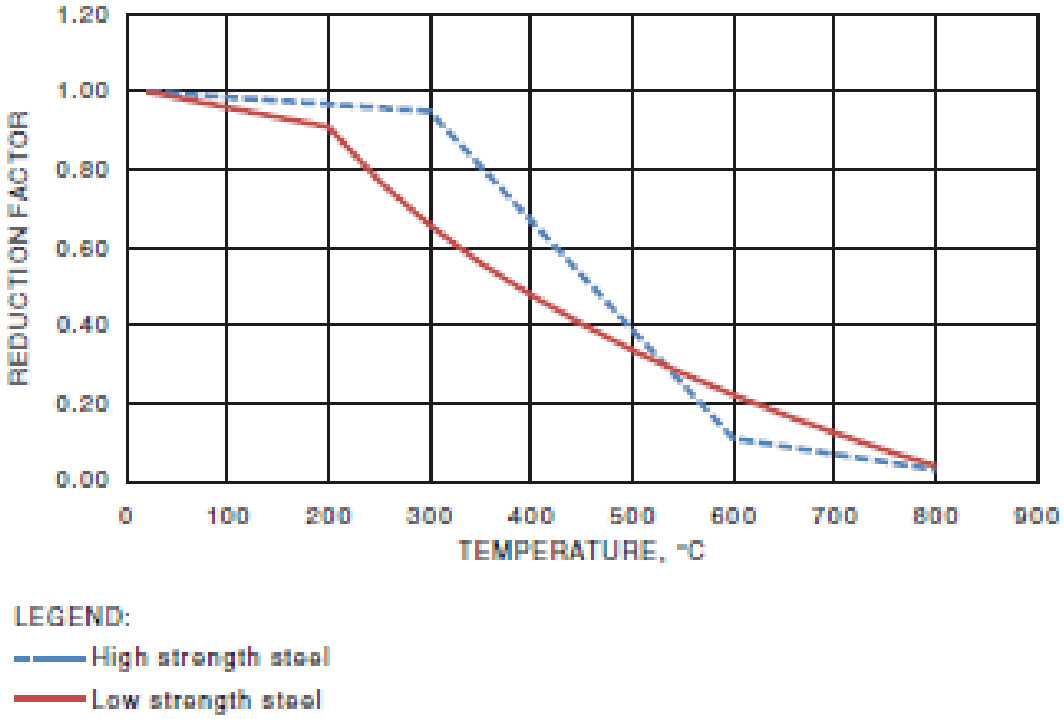

FIGURE 9.4.2 VARIATION OF YIELD STRESS OF STEEL WITH TEMPERATURE

9.4.3 Variation of Modulus of Elasticity with Temperature

The influence of temperature (T) is defined by a reduction factor $\left(\frac{E_T}{E_{20}}\right)$ as follows.

The relationship is shown in figure 9.4.3.

For all steels ro AS 1397:

$$20\ °C \le T < 300\ °C \quad \frac{E_T}{E_{20}} = -0.000835\,T + 1.0167 \qquad \text{...9.4.3(1)}$$

$$300\ °C \le T < 800\ °C \quad \frac{E_T}{E_{20}} = -0.00135\,T + 1.1201 \qquad \text{...9.4.3(2)}$$

where

$f_{y,T}$ = modulus of elasticity at $T\,°C$

$f_{y,20}$ = modulus of elasticity at 20 °C

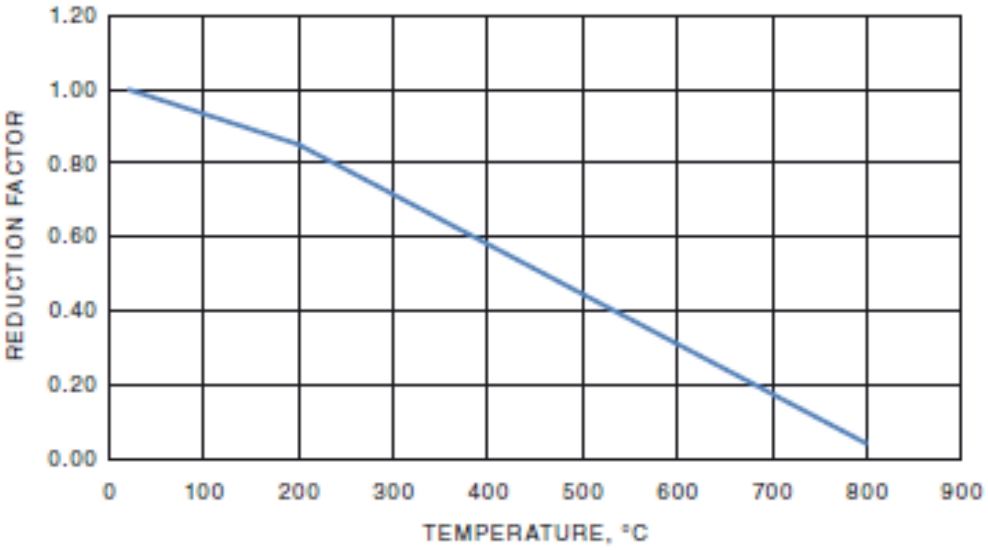

FIGURE 9.4.3 VARIATION OF MODULUS OF ELASTICITY WITH TEMPERATURE

9.4 Variation of stress-strain relationship with temperature

The influence of temperature (T) on the stress-strain relationship for cold-formed steels shall be taken as follows. For low strength steels at 100°C and 200°C with a well-defined yield point, the elastic-perfect plastic material model is recommended as follows:

$$\varepsilon_T = \frac{f_T}{E_T} + \beta\left(\frac{f_{y,T}}{E_T}\right)\left(\frac{f_T}{f_{y,T}}\right)^{\eta_T} \quad \text{...9.4.4(1)}$$

where

ε_T = strain corresponding to given stress f_T at temperature (T)

E_T and $f_{y,T}$ = modulus of elasticity and yield stress at temperature (T), respectively, and η_T and β are two parameters

For high strength steels to AS 1397: $20\ °C \le T \le 800\ °C$

$$\beta = 0.86 \quad \text{...9.4.4(2)}$$
$$\eta_T = -3.05\times10^{-7}T^3 + 0.0005\,T^2 - 0.2615\,T + 62.253$$

For low strength steels to AS 1397: $300\ °C \le T \le 800\ °C$

$$\beta = 1.5 \quad \text{...9.4.4(3)}$$
$$\eta_T = 0.000138\,T^2 - 0.085468\,T + 19.212$$

9.4.5 Variation of specific heat with temperature

The influence of temperature (T) on the specific heat (c_p) in $J/kg\,°C$ shall be taken as follows:

$$20\ °C \le T < 600\ °C \quad c_p = 425 + 7.73\times10^{-1}T - 1.69\times10^{-3}T^2 + 2.22\times10^{-6}T^3 \quad \text{...9.4.5)}$$

$$600\ °C \le T < 735\ °C\ \ c_p = 666 + \frac{13002}{(738 - T)} \qquad \text{...9.4.5(2)}$$

$$735\ °C \le T < 900\ °C\ \ c_p = 545 + \frac{17820}{(T - 731)} \qquad \text{...9.4.5(3)}$$

$$900\ °C \le T < 1200\ °C\ \ c_p = 650 \qquad \text{...9.4.5(4)}$$

9.4.6 Variation of thermal conductivity with temperature

The influence of temperature (T) on thermal conductivity (k) in $W/m°C$ shall be taken as follows:

$$20\ °C \le T < 800\ °C\ \ k = 54 - 3.33 \times 10^{-2} T \qquad \text{...9.4.6(1)}$$

$$800\ °C \le T \le 1200\ °C\ \ k = 27.3 \qquad \text{...9.4.6(2)}$$

9.4.7 Variation of relative thermal elongation with temperature

The influence of temperature (T) on the thermal elongation $\left(\frac{\Delta l}{l}\right)$ shall be taken as follows, where Δl is the thermal elongation and l is the length at 20°C.

$$20\ °C \le T < 750\ °C\ \ \frac{\Delta l}{l} = 1.2 \times 10^{-5} T + 0.4 \times 10^{-8} T^2 - 2.416 \times 10^{-4} \qquad \text{...9.4.7(1)}$$

$$20\ °C \le T < 750\ °C\ \ \frac{\Delta l}{l} = 1.1 \times 10^{-2} \qquad \text{...9.4.7(2)}$$

$$20\ °C \le T < 750\ °C\ \ \frac{\Delta l}{l} = 2 \times 10^{-5} T - 6.2 \times 10^{3} \qquad \text{...9.4.7(3)}$$

9.5 DETERMINATION OF MEMBER CAPACITIES AT ELEVATED TEMPERATURES

9.5.1 Members subject to uniform temperature distributions

For members subject to uniform or near uniform temperature dismbutions in applications such as beams or columns, ambient temperature design capacity rules shall be used with appropriately reduced mechanical properties in accordance with Clause 9.4. For those made of steels with high levels of nonlinearity in the stress-strain curves at temperatures in the range of 400°C to 700°C, use other methods given in Clause 9.3 to calculate PSA [Methods (a) and (b)). A high level of nonlinearity may be assumed when the ratio of proportional limit to yield stress is less than 0.75 and is present normally for low strength steels.

9.5.2 Members subject to non-uniform temperature distributions

The net eccentricity due to neutral axis shift and thermal bowing and their magnification effects shall be used in calculating the resulting bending moment

on a wall stud.

NOTE: Appendix G gives guidance on the determination of the load-bearing capacity of cold-formed steel structural members used in floors or load-bearing walls at a time equal to FRL in the standard fire test by using its temperature-time relationship obtained in accordance with Clause 9.7 and the elevated temperature mechanical properties in accordance with Clause 9.4.

9.6 DETERMINATION OF LIMITING TEMPERATURE

The maximum temperature in the cross-section shall be used as the limiting temperature except in floor systems where the average temperature in the cross-section shall be used. Standard fire tests or advanced analyses as defined in Clause 9.3 or both shall be used to establish a relationship between limiting temperature and load ratio. For cold-formed steel structural members, a conservative limiting temperature of 350°C shall be used.

9.7 DETERMINATION OF TEMPERATURE-TIME RELATIONSHIPS FOR PROTECTED MEMBERS

The temperature-time relationship of protected cold-formed steel structural members shall be obtained from the standard fire test conducted in accordance with AS 1530.4 and be used without modification provided—

(a) the cold-formed steel structural member is the same as the prototype;
(b) the exposed surface area to mass ratio is equal or greater than that of the prototype;
(c) the fire protection system is equal to or superior to that of the prototype; and
(d) the fire exposure condition is the same as the prototype.

Alternatively, advanced thermal analysis as defined in Clause 9.3 of the cold-formed steel structural member and its fire protection system may be used to derive the temperature-time relationship. provided it has been previously validated using standard fire test data.

9.8 DETERMINATION OF PSA FROM THE STANDARD FIRE TEST

The period of structural adequacy (PSA) of cold-formed steel structural members shall be obtained from the standard fire test conducted in accordance with AS 1530.4 and may be used without modification provided—

(a) the cold-formed steel structural member is the same as the prototype;
(b) the exposed surface area to mass ratio is equal or less than that of the prototype:
(c) the fire protection system is equal to or superior to that of the prototype:
(d) the fire exposure condition is the same as the prototype:
(e) the support conditions are the same as the prototype and the restraints

are not less favourable than those of the prototype; and

(f) the load ratio is less than or equal to that of the prototype.

9.9 CONNECTIONS

Connections shall be protected with the maximum thickness of fire protection material required for any of the members framing into the connection to achieve their respective FRLs. This thickness shall be maintained over all connection components.